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(54) Title: IDENTIFICATION OF A VIRTUAL RASTER PATTERN

(57) Abstract: A method aims to identify a virtual raster pattern in an image of a surface that is provided with a plurality of position-coding marks. Each mark is associated with a respective intersection of raster lines belonging to the raster pattern. By means of the method, the virtual raster pattern is identified via Fourier analysis of the image. A computer program product and a device for position determination are also described.

IDENTIFICATION OF A VIRTUAL RASTER PATTERN

Technical Field

The present invention relates in general to identi-
fication of raster patterns, in particular in connection
with position coding on a surface that is provided with
a plurality of position-coding marks. In particular, the
5   invention relates to identification of a virtual raster
pattern in an image of this surface, on which each mark
is associated with a respective intersection of raster
lines belonging to the virtual raster pattern.

Background Art

In many connections it is desirable to be able to
10   determine an absolute position on a surface. One example
is the digitising of drawings. Another example is the
production of an electronic version of handwritten infor-
mation.

Examples of previously known devices for position
15   determination are found in US-A-5,852,434, where a device
for determining an absolute position is described. The
device comprises a writing surface which is provided with
a position-coding pattern by means of which x-y-coordi-
nates can be determined, a detector that can detect the
20   position-coding pattern and a processor that can deter-
mine the position of the detector in relation to the
writing surface on the basis of the detected position-
coding pattern. The device makes it possible for a user
to enter handwritten and hand-drawn information into a
25   computer while the information is being written or drawn
on the writing surface.

Three examples of position coding are given in
US-A-5,852,434. The first example consists of symbols,
each of which is constructed of three concentric circles.
30   The outermost circle represents the x-coordinate and the
middle the y-coordinate. Both the outer circles are fur-
ther divided into 16 parts which, depending upon whether

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they are filled in or not, indicate different numbers. This means that each pair of coordinates, x, y, is coded by a complex symbol with a special appearance.

In the second example, the coordinates in each point
5 on the writing surface are indicated by means of a bar code stack, a bar code for the x-coordinate being indicated above a bar code for the y-coordinate.

A third example consists of a checked pattern that can be used to code the x- and y-coordinates. There is,
10 however, no explanation as to how the checked pattern is constructed or how it can be converted into coordinates.

A problem with the position-coding pattern of US-A 5,852,434 is that it is constructed of complex symbols and the smaller the symbols are made, the more dif-
15 ficult it becomes to produce the patterned writing surface and the greater the danger of incorrect position determinations, while the larger the symbols are made, the poorer the position resolution becomes.

A further problem is that the processing of the
20 detected position-coding pattern by the processor becomes rather complicated, due to the fact that complex symbols are to be interpreted.

Yet another problem is that the sensor must be designed in such a way that it can record four symbols at
25 the same time, so that it is certain to include at least one symbol in its entirety, which is necessary in order for the position determination to be carried out. The ratio between the required sensor area and the area of the position-coding pattern that defines a position is
30 thus large.

In the international Patent Application PCT/SE00/01895, which is assigned to the present Applicant, a position code is described which solves the above-mentioned problems. The position code consists of
35 a raster and marks which are positioned at each raster point. The marks are preferably essentially the same size, round and displaced in relation to the raster

points in one of four orthogonal directions. The raster
is virtual and is thus invisible both to the eye and to
sensors.

In order to decode the above-mentioned position

5   code, it is necessary for the virtual raster to be iden-
tified. The identification of the raster is the object of
the present invention.

Summary of the Invention

The object of the present invention is thus to indi-
cate a method for identifying a virtual raster pattern in

10   an image of the type described by way of introduction.

A special object is to make possible the identifi-
cation of a regular virtual raster pattern in an image
that is recorded with an unknown rotation and/or an
unknown perspective between the imaging sensor and the

15   imaged surface.

These and other objects which will be apparent from
the following description are achieved completely or par-
tially by a method according to claims 1 and 26, a com-
puter program product according to claim 27 and a device

20   for position determination according to claim 28. Prefer-
red embodiments are defined in the subclaims.

According to the invention, some form of Fourier
analysis is used for identification of the virtual raster
pattern. This provides a plurality of important advan-

25   tages. During the Fourier analysis, the whole image or a
subset thereof is processed as a single unit. In this way
identification can be implemented with low sensitivity to
local interference, for example noise in the image or
dirt on the imaged surface. The use of Fourier analysis

30   also makes possible effective and unambiguous compensa-
tion for an unknown rotation and/or an unknown perspec-
tive between the imaging sensor and the imaged surface.

The above-mentioned Fourier analysis comprises clas-
sical Fourier analysis, which, however, is normally very

35   calculation-intensive and is often replaced by FFT, Fast

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Fourier Transformation, which can also be used in the
present invention.

According to a preferred embodiment, before the
Fourier analysis of the image, a conversion is carried
5   out of the image into a set of discrete unit pulses that
are placed at the positions of the marks in the image.
Thus a classical Fourier analysis can be used, which is
simplified as far as calculation is concerned. A double
integral is thereby replaced by a sum of the discrete
10 unit pulses, whereby the number of operations required is
reduced. The identification via Fourier analysis can thus
be implemented in an efficient way, as far as calculation
is concerned, and can be implemented in a rapid program
code which can be executed in real time by a processor
15 that draws little current.

Each unit pulse is preferably placed at the centre
of gravity of the corresponding mark. This means that
each mark corresponds to a single location which is unam-
biguous and essentially independent of the shape of the
20 mark. This minimises the effect of blur in the image
caused by movement or the image not being in the focus
of the optical system.

According to a preferred embodiment, the Fourier
analysis comprises the steps of calculating a spatial
25 frequency spectrum in two dimensions on the basis of the
image, of identifying at least two main vectors in the
image, based on the frequency spectrum, and identifying
the raster lines of the raster pattern on the basis of
the main vectors. The main vectors resulting from the
30 Fourier analysis represent the dominant directions in the
image, in particular the perpendiculars to the directions
of the raster lines, and the lengths of the main vectors
correspond to the image's dominant spatial frequencies
along the main vectors. In an orthogonal uniform raster
35 pattern, the main vectors are thus two mutually orthogo-
nal vectors with a length corresponding to the distances
between the raster lines.

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It should be noted that within the scope of the invention, the term "spatial frequency spectrum" also comprises its inverse, that is a "spatial wavelength spectrum".

5   It is preferable for the spatial frequency spectrum to be calculated on the basis of a central part of the image. The adverse effect of any perspective in the image is thereby minimised. If the image contains a perspective, the spatial frequencies will vary across the image,
10   and in particular in the peripheral parts thereof. In addition, the calculation time is reduced, since a subset of the image is evaluated. In certain cases, the choice of the central part also results in lower requirements concerning image quality and/or illumination of the sur-
15   face that is being imaged.

According to a preferred embodiment, the main vectors are identified by localising in the spatial frequency spectrum positions of peaks that exceed a given threshold value, and selecting main vectors on the basis
20   of these positions.

It should also be noted that, even if it is possible, it is not necessary to calculate a complete spatial frequency spectrum in two dimensions, that is for all possible directions and spatial frequencies in the
25   image. The spatial frequency spectrum is calculated or "sampled", however, preferably based on a two-dimensional Fourier transform along at least two directions in the image.

According to an additional preferred embodiment, the
30   calculation of the spatial frequency spectrum and identification of the main vectors therein are carried out by changing the direction of a direction vector in steps within an angle range, calculating at least one absolute value of the two-dimensional Fourier transform for
35   the image on the basis of each such direction vector, and identifying the absolute values that exceed said threshold value. The angle range, which is typically

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180° or less since a larger angle range results in
redundant information, is searched typically in steps
of approx. 2°-4°, although smaller or larger steps can
be uséd in certain applications. The threshold value
5   is typically 30-70% of the theoretical maximum absolute
value, which is proportional to the number of marks in
the subset of the image that is subjected to the Fourier
analysis. The maximum absolute value can thus be calcu-
lated for each subset.
10   It is preferable that, while searching through
the angle range, the length of the direction vector
is changed within a frequency range that comprises the
nominal spatial frequency of the raster pattern, that is
the spatial frequency of the raster pattern on the imaged
15   surface. The frequency range is suitably selected so that
it contains all possible spatial frequencies that can
arise as a result of the imaging relationship (rotation/
perspective) between the imaging sensor and the imaged
surface. For an image in the form of a set of unit
20   pulses, the calculation of the Fourier transform for each
new length of a given direction vector involves only one
extra addition step, which can be carried out in a way
that is efficient as far as calculation is concerned. The
length of the direction vector is preferably changed in
25   steps that are inversely proportional to some suitable
power of 2, for example eighths (2^{-3}), as the step length
can then be calculated by a time-efficient bit shift. It
is possible that the stepwise change of the length of the
direction vector is discontinued upon the identification
30   of one or more absolute values that exceed the threshold
value, and that the direction of the direction vector is
changed within the angle range for calculation of a new
absolute value of the two-dimensional Fourier transform.
         The position of each of the peaks is suitably local-
35   ised by calculation of the centre of gravity of the abso-
lute values that exceed the threshold value and that are
adjacent to each other in the spatial frequency spectrum.

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This provides a relatively accurate position determina-
tion for the peaks, even with coarse searching of the
angle range.

According to a preferred embodiment, the partial
5   step of selecting at least two main vectors comprises
having each peak position identify a candidate vector,
having at least one current image transform, which pro-
vides a given change in the relationship between two vec-
tors, operate on the candidate vectors, and selecting as
10   main vectors the candidate vectors that attain a required
mutual relationship for said at least one current image
transform. This partial step is implemented in order to
establish which of the localised peak positions repre-
sent main vectors. The peak positions can, in addition to
15   main vectors, represent second order dominant patterns in
the image, for example, diagonal patterns, or patterns
resulting from interference/noise.

The image transform is suitably a transform, for
example elliptical, that changes both the length ratio
20   and the angle ratio between the vectors. In this case,
the required mutual relationship is a length and angle
ratio which corresponds to the relationship between the
raster lines in the original raster pattern, that is the
virtual raster pattern on the imaged surface. For exam-
25   ple, if the original raster pattern is an orthogonal uni-
form raster pattern, the image transform should thus
transform the main vectors to an orthogonal angle ratio
with the length ratio 1:1. If one of the candidate vec-
tors corresponds to a diagonal direction in the image,
30   then the angle ratio should thus be 45° and the length
ratio should be $1:\sqrt{2}$.

It is possible to have a series of different current
image transforms operate sequentially on the candidate
vectors, at least until a required mutual relationship
35   is obtained between the candidate vectors. Alternatively,
the current image transform can be selected adaptively,
more particularly on the basis of an earlier image trans-

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form that gave rise to the required relationship for a
previous image.

It is preferable that each current image transform
corresponds to a given imaging relationship between the
5   imaging sensor and the imaged surface. In an embodiment
that is very efficient as far as calculation is concerned
but is relatively inaccurate, the imaging relationship is
derived by finding which image transform gives rise to
the required relationship between the candidate vectors,
10   whereby rotation and perspective in the image are mini-
mised on the basis of this imaging relationship.

According to an alternative embodiment, the main
vectors are selected instead on the basis of earlier
main vectors which were determined for a previous image.
15   It is possible to make the main vectors identical to the
earlier main vectors, or to use weighted information
about these earlier main vectors during the identifica-
tion of the main vectors, for example in order to make
the localisation of peaks in the spatial frequency spec-
20   trum more effective.

According to a preferred embodiment, the marks are
transformed with the identified main vectors as the bases
for the production of a rotation-corrected image in which
rotation of the marks over the plane of the image is
25   essentially eliminated.

According to a further preferred embodiment, a com-
pensation for the perspective is effected in the thus
rotation-corrected image. This compensation can be pre-
ceded by a needs test, in which the width is determined
30   of the peaks corresponding to the main vectors in a spa-
tial frequency spectrum of said rotation-corrected image.
If the width exceeds a given width value, perspective
compensation is carried out. The width of the peaks can
be determined in a way that is efficient as far as cal-
35   culation is concerned, since the positions of the peaks
in the spatial frequency spectrum are essentially known
from preceding processing steps.

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The perspective compensation suitably comprises mea-
suring an inclination variation for the raster pattern
along each main vector in the rotation-corrected image,
calculating a perspective transform that essentially eli-

5   minates the inclination variation on the basis of the
measured inclination variation, and producing a perspec-
tive-corrected image by means of the perspective trans-
form. This is an efficient way to calculate a perspec-
tive-corrected image with a high degree of accuracy.

10   In this connection, it is preferable that the mea-
surement of the inclination variation for the raster pat-
tern along a selected main vector comprises, via Fourier
analysis of at least two subsets of the rotation-correct-
ed image distributed along the selected main vector, cal-

15   culating at least one subset main vector for each subset,
identifying an initial position in the associated subset
for each subset main vector, and calculating the inclina-
tion variation along the selected main vector on the
basis of the subset main vectors and the initial posi-

20   tions. The identification of the subset main vectors via
Fourier analysis can be achieved quickly by starting from
the known main vectors. In general, the subset main vec-
tors are situated close to the main vectors.

The initial position is preferably identified on the

25   basis of the centre of gravity of the marks incorporated
in the respective subset. This means that the identifica-
tion of the initial position is only affected to a small
extent by imaging errors, such as high degree of perspec-
tive, missing marks, additional marks, noise, etc. Alter-

30   natively, the initial position could be set as the mid-
point of the subset, whereby the calculations required
are minimised.

A further preferred embodiment comprises the steps
of measuring the phase displacement along the respective

35   main vector via Fourier analysis of the rotation-correct-
ed or perspective-corrected image, and on the basis of
the measured phase displacements localising the raster

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pattern relative to the marks in the image. The phase
displacement is suitably obtained as the phase angle for
the two-dimensional Fourier transform of the image for
the main vectors and can easily be eliminated by a trans-
5   formation operation. The directions of the raster lines
are then given by the perpendiculars to the main vectors,
and the distance between the intersections of the raster
lines along the main vectors is given by the lengths of
the main vectors.

10   In certain cases, it is desirable to calculate a
normalising transform that places the intersections of
the raster pattern a given distance apart, for example,
at integer coordinates, and to operate the normalising
transform on the image in order to produce a normalised
15   image.

According to another aspect of the present inven-
tion, this relates to a computer-readable computer pro-
gram product which comprises a computer program with
instructions for causing the computer to implement the
20   method for identification as described above. This com-
puter program product can, for example, comprise a non-
volatile memory for a computer, such as a floppy disk or
CD ROM, or a volatile memory in a computer. The computer
program product can alternatively comprise propagating
25   signals, such as a bit stream for packet transfer via the
Internet or the like, or carrier waves that are transmit-
ted to the computer by cable-based or wireless means.

According to a further aspect of the present inven-
tion, this relates to a device for position determina-
30   tion. The device comprises a sensor for producing an
image of a partial surface of a surface which is provided
with a position code in the form of a plurality of marks,
each of which is associated with one of a plurality of
intersections belonging to a virtual raster pattern, and
35   an image-processing means which is arranged to calculate
a position for the partial surface based on a subset of
the surface. The image-processing means is thereby

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designed to identify the virtual raster pattern in accor-
dance with the method above.

The advantages of the computer program product and
the device for position determination are apparent from
5   the above description. The features described in asso-
ciation with the method for identifying a virtual raster
pattern are, of course, also applicable to the device for
position determination.

Brief Description of the Drawings

In the following, the invention will be described
10   for the purpose of exemplification with reference to the
accompanying drawings which show a currently preferred
embodiment and in which

Figs 1A-1B show an example of a surface with a
position-coding pattern and an image of the same respec-
15   tively,

Fig. 2 illustrates some of the processing steps that
are implemented for identification of the virtual raster
pattern in the image according to Fig. 1B,

Fig. 3 shows the two-dimensional Fourier transform
20   of the image according to Fig. 1B, with the actual calcu-
lation dots marked by black symbols,

Fig. 4 shows the image according to Fig. 1B after
rotation compensation,

Figs 5A-5D show two-dimensional Fourier transforms
25   of subsets of the image according to Fig. 4, with the
actual calculation dots marked by black symbols,

Fig. 6 is a diagram of the calculated inclination
variation along two main vectors in the image according
to Fig. 4,

30   Fig. 7 shows the image according to Fig. 4 after
elimination of perspective,

Fig. 8 shows a two-dimensional Fourier transform of
the image according to Fig. 7, with the actual calcula-
tion dots marked by symbols,

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Fig. 9 shows the image according to Fig. 7 after
compensation for displacement along the main vectors, the
original orthogonal raster pattern being identified,

Fig. 10 shows a device that can be used for position
5   determination,

Fig. 11 shows a position-coding pattern with a tri-
angular raster pattern, and

Fig. 12 shows a position-coding pattern with a hexa-
gonal raster pattern.

Description of Preferred Embodiments
10   Fig. 1a shows a part of a product 1 which on at
least part of its surface 2 is provided with an optical-
ly readable position-coding pattern 3 which makes pos-
sible position determination. The position-coding pat-
tern 3 comprises marks 4 which are systematically arrang-
15   ed across the surface, so that this has a "patterned"
appearance. The position determination can be carried out
on the whole surface of the product. In other cases, the
surface that permits position determination can consti-
tute a smaller part of the product. The product can, for
20   example, be used to produce an electronic representation
of information that is written or drawn on the surface.
The electronic representation can be produced by deter-
mining the position of a pen on the paper continually
while writing on the surface with the pen, by reading off
25   the position-coding pattern.

More particularly, the position-coding pattern com-
prises a virtual raster 5 (indicated by broken lines in
Fig. 9), which is neither visible to the human eye nor
can be detected directly by a device for determining
30   positions on the surface, and the marks 4, each of which
represents one of four values dependent upon its loca-
tion. The value of a mark 4 depends upon its location in
relation to its nominal position 6 (Fig. 9), which can
also be called its virtual raster point and is repre-
35   sented by the intersection between the raster lines 7
(Fig. 9). The mark 4 is the shape of a circular dot. In

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the example in Fig. 9 there are four possible locations,
one on each of the raster lines 7 extending from the
nominal position 6. The displacement from the nominal
position 6 is the same size for all values. In this case,
5   the virtual raster 5 is orthogonal and has the same pitch
in both its main directions or raster directions. In this
connection it should be pointed out that the position-
coding pattern in Fig. 1A and Fig. 9 have been greatly
enlarged for the sake of clarity. In addition, it is
10 shown on only a part of the product.

        For details concerning the generation of the posi-
tion-coding pattern and the decoding of the same for
position determination, reference is made to the Appli-
cant's Swedish Patent Application PCT/SE00/01895.

15   In order for the position code to be able to be
detected, the virtual raster needs to be determined. This
must be carried out with high accuracy and in real time,
based on an image of a partial surface with a number of
marks 4. Fig. 1B shows such an image of the partial sur-
20 face 8 in Fig. 1A. For the sake of clarity, the imaged
marks are somewhat larger than the other marks in
Fig. 1A. In the image according to Fig. 1B the pattern is
distorted due to the sensor not being held parallel with
the imaged partial surface. The image therefore contains
25 both an unknown perspective, due to tilting of the sensor
relative to the partial surface, and an unknown rotation
in the image plane, due to rotating or skewing of the
sensor around its perpendicular axis.

        Fig. 2 indicates the main steps for the recreation
30 of the original dot pattern and identification of the
virtual raster based on a recorded image. The main steps
comprise preprocessing of the image (step 100), detection
of the image's main vectors via Fourier analysis (step
101), compensation for rotation in the image plane by
35 projection of the marks along the main vectors (step
102), detection of the perspective in the rotation-
corrected image via Fourier analysis (step 103), removal

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of the detected perspective by transformation (step 104),
detection of the phase content in the perspective-cor-
rected image via Fourier analysis (step 105) and finally
removal of the phase content by transformation to produce
5   a recreated dot pattern with the associated virtual
raster (step 106).

In the following, each of the main steps will be
described in greater detail.

Preprocessing (Step 100)

The aim of the preprocessing is to identify all
10   the marks 4 in the image. This can be carried out using
thresholds, so that a mark is identified by one or more
picture elements (pixels) with a value that exceeds a
predetermined or calculated threshold value. The centre
of gravity is calculated for all such picture elements
15   belonging to a mark and is used in the subsequent pro-
cessing. Thus, the appearance of the mark in the image
has as little effect as possible on the mark's subse-
quently calculated displacement from the nominal posi-
tion. The image is then converted to a set of dots by
20   the marks being replaced by unit pulses (so-called Dirac
pulses, δ) which are placed at the centres of gravity of
the marks.

When the set of dots has been defined, a number of
partial steps are implemented that are based on Fourier
25   analysis of the image, or rather the above-mentioned set
of dots.

The general two-dimensional Fourier transform of an
image $f(x,y)$ is of the form:

$$F(u,v) = \iint\limits_{image} f(x,y) \cdot e^{-2 \cdot \pi \cdot i \cdot (ux+vy)}$$

30   Since the image is converted to a set of dots, the
Fourier transform is given by the expression:

15

$$F(u,v) = \iint_{image} \delta(x - x_j, y - y_k) \cdot e^{-2 \cdot \pi \cdot i \cdot (u \cdot x + v \cdot y)}$$

$$= \sum_{j,k} e^{-2 \cdot \pi \cdot i \cdot (u \cdot x_j + v \cdot y_k)}$$

where the set of dots is {x_j, y_k}, and (u,v) is a direction vector, since the integral of a Dirac pulse is one (1), and the image function between the Dirac pulses is
5   zero (0).

This expression can be calculated relatively quickly, as the number of operations is only equal to the number of detected dots, that is normally of the order of 100.

Detection of Main Vectors (Step 101)
10   After the preprocessing of the image, the set of dots is analysed to detect its main or raster vectors, that is its dominant directions and dominant spatial frequencies. This is carried out by the calculation of the Fourier transform of the set of dots for different
15   direction vectors (u,v). The absolute values of the calculated Fourier transforms |F(u,v)| give a spatial frequency spectrum in two dimensions.

Fig. 3 shows a spatial frequency spectrum for the set of dots in Fig. 1b. Dark areas indicate higher spec-
20   tral amplitudes. The central dark area forms the origin, that is (u,v) = (0,0). Instead of calculating the whole two-dimensional frequency spectrum as shown in Fig. 3, the Fourier transform is calculated at a number of dots, that is for a number of different direction vectors
25   (u,v). These dots are marked in Fig. 3. More particularly, a band-shaped area in a half plane of the frequency domain is "swept" in steps. Several sums are calculated along one and the same search direction. With the aim of making the calculations more efficient, only scaling is
30   carried out along the search direction, and the scalar product ($u_0 \cdot x_j + v_0 \cdot y_k$) is calculated only once per direction vector (u_0, v_0). The scaling is carried out itera-

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tively and gives rise to only one extra addition per step
and dot in each search direction.

In pseudo-code this can be written:

```
for dot=1 to N
        α0=u0·dot.x+v0·dot.y
        dα0=α0/8
        for s=0 to 11
                dsum=exp (-2·π·i·α0)
                sum(s) = sum(s) + dsum
                α0=α0+dα0
        next s
next dot
```

In each search direction, steps can suitably be used
that are inversely proportional to any suitable power of
2 (2^n), for example, eighths as above, as the calculation
of the step $(d\alpha_0)$ is thereby reduced to a bit shift that
is efficient as far as calculation is concerned.

The width of the search band in the frequency plane
is determined based on how much the imaging distortion
can be assumed to change the spatial frequencies of the
original pattern (Fig. 1A) along the main vectors. This
depends in turn upon in what locations the imaging sensor
can be expected to be placed. Normally the search band
extends on both sides of the pattern's nominal spatial
frequencies, that is the distance between the raster
lines in the original pattern. Of course, the size of
the steps in each search direction and the steps in the
sweep direction varies depending upon available processor
power, required calculation time and required accuracy.

From the above, it can be seen that the searching in
the frequency plane is carried out by the calculation of
a number of independent sums. The searching is thus of a
parallel nature and is therefore well suited for imple-
mentation in hardware, such as an ASIC.

After or during the calculation of this "sampled"
spatial frequency spectrum in two dimensions, candidate

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vectors c1-c3 are identified, based on the values of the
calculation dots. All calculation dots with a value above
a threshold value are considered to be significant (mark-
ed with black crosses in Fig. 3) and are used for the
5   calculation of the coordinates for the candidate vectors
c1-c3. The threshold value is determined as a percentage,
for example 50%, of the theoretically maximum amplitude
value, which is proportional to the number of marks in
the image. The number of marks is known from the prepro-
10   cessing step. If several significant calculation dots are
adjacent to each other in the frequency plane, the centre
of gravity of these is considered to give the coordinate
for a candidate vector c1-c3 in the frequency plane (can-
didate vectors which later prove to be main vectors or
15   diagonal vectors are marked by white and black stars
respectively in Fig. 3).
        It must be pointed out that all dots in the set of
dots are not used for the above calculation, but only
those that are closest to the centre of the image. Typi-
20   cally, approximately 50% of the available dots are used.
This is done principally for two reasons. If all the dots
were to be included, there is a danger that the peaks in
the frequency plane (Fig. 3) would become too wide, and
thereby difficult to detect, particularly with a high
25   degree of perspective. This is because the perspective
gives rise to great frequency changes in peripheral parts
of the image. At the centre of the image, however, the
spatial frequencies correspond relatively well to the
spatial average frequencies in the image. In addition,
30   the problem is avoided of insufficient illumination of
the periphery of the image, and the resulting high noise
levels. In addition, the calculation time is reduced in
proportion to the reduction in the number of dots.
        After the above calculation step, a number of peaks
35   have been detected in the frequency plane. However, it
remains to be determined which of the detected peaks cor-
respond to main vectors. If the image is recorded without

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perspective between the sensor and the patterned product, the diagonal vector can be distinguished in that it has a length that is $\sqrt{2}$ times longer than the main vectors, which in addition are orthogonal to each other. This does

5 not apply, however, with more extreme perspectives, such as in Fig. 1B, where the main vectors are not orthogonal, and neither is the length ratio between the diagonal vector and the main vector $\sqrt{2}$. In addition, one or more invalid maximums may have been detected in the frequency

10 plane, for example as a result of interference or noise in the image.

For the identification of main vectors a number of image transforms are used, typically approximately 25, corresponding to a number of given imaging relationships

15 between the sensor and the product. In the case of a pen, this can in fact be physically angled and rotated relative to the product in a limited number of ways. The image transforms restore a given distorted frequency domain to an orthogonal and uniform frequency domain,

20 that is a frequency domain where the main vectors actually are orthogonal and where the length ratio between a diagonal vector and a main vector is $\sqrt{2}$. The image transforms typically give rise to a so-called elliptical transformation.

25 After identification of the candidate vectors c1-c3, these candidate vectors c1-c3 are operated on by the image transforms and it is measured how well the properties (direction and length) of the transformed candidate vectors appear to correspond to those of the true main

30 vectors.

The above can be implemented by having all the image transforms operate on all candidate vectors c1-c3, by the transformed candidate vectors being allocated ratings based on their mutual relationships, and by the main

35 vectors being identified as the transformed candidate vectors that received the highest ratings. If necessary,

19

the image transform that gave rise to the highest ratings
can also be identified.

An alternative which is more efficient as far as
calculation is concerned is to divide the calculation

5   into two partial steps. In the first partial step, a
sequence of image transforms may operate on all pairs
of candidate vectors c1-c3, in order to identify all
potential pairs of main vectors and the image transforms
that gave rise to these potential pairs. After transfor-

10   mation, potential pairs of main vectors have an orthogo-
nal mutual angle ratio, a mutual length ratio of 1:1 and
given lengths. These criteria are of course determined
within given tolerances. The criterion that the vectors
must have given lengths after transformation is intended

15   to exclude two mutually orthogonal diagonal vectors being
mistaken for main vectors. In this first partial step,
the operation of different image transforms on a given
pair of candidate vectors is suitably discontinued when
this given pair is identified as a pair of potential main

20   vectors, whereupon the sequence of image transforms may
operate on a new pair of candidate vectors. This reduces
the number of operations required. In the second partial
step, the image transforms that gave rise to the poten-
tial pairs may operate on any additional candidate vec-

25   tors, whereupon these additional candidate vectors are
allocated ratings in accordance with their correspondence
with diagonal vectors. The main vectors can then be iden-
tified as the pair of candidate vectors that received the
highest ratings. The division into two partial steps

30   means that the sometimes relatively calculation-intensive
ratings evaluation only needs to be implemented for a
small number of pairs of candidate vectors and a small
number of image transforms.

According to a further alternative, a sequence of

35   image transforms may operate on all pairs of candidate
vectors. If sufficiently high ratings are obtained for a

20

particular image transform, then this is selected, other-
wise the next image transform in the sequence is tested.

In this connection, it is possible to test the image
transforms adaptively, that is for example on the basis
5   of the user's identity and/or the image transform that
was selected for a previous image. It is, in fact, prob-
able that consecutive images have been imaged under simi-
lar conditions. One and the same user also probably car-
ries out the imaging in a similar way each time.

10   It is worth noting that the image transforms and the
associated calculations are simple to carry out as only
the actual candidate vectors are transformed, and not
the whole set of dots. The image transforms can be 2x2
matrices, and the number of operations is thus four per
15   image transform and pair of candidate vectors.

As each image transform corresponds to a known rela-
tionship between the sensor and the product, the above
detection step provides an indication of how the sensor
is held relative to the product. With low accuracy
20   requirements, this information can be used immediately
in order to compensate for perspective and rotation in
the image. Often, however, a more accurate compensation
is required.

According to an alternative procedure, searching for
25   peaks in the frequency plane is not carried out. Instead,
an image transform is selected initially that is operated
on the set of dots or a subset thereof. Thereafter, the
main vectors of the transformed set of dots are identi-
fied via Fourier analysis, suitably by the above-mention-
30   ed searching for peaks in the frequency plane. If no
satisfactory result is obtained, a new image transform is
selected, whereupon a new identification of main vectors
is implemented via Fourier analysis. This method is, how-
ever, relatively calculation-intensive, particularly if
35   the image conditions change frequently between consecu-
tive images. To minimise the number of image transforms
that must be tested, the selection of image transform is

suitably based on the user's identity and/or the image
transform selected for a previous image.

Compensation for Rotation (Step 102)

     In order to compensate for rotation of the set of
dots in the image plane, the set of dots is projected

5   along the main vectors detected as described above. A set
of dots is thereby obtained which is principally aligned,
even though there can still remain a non-linear interfe-
rence in the form of a perspective in the image.

     Fig. 4 shows the set of dots in Fig. 1B after such

10 an alignment. In order to show clearly the remaining per-
spective, the corresponding virtual raster has also been
marked by broken lines. It should be noted that this
raster has been calculated based on parameters that are
determined in the immediately-following detection of per-

15 spective (step 103).

Detection of Perspective and Compensation for this
(Steps 103-104)

     A general characteristic of perspective is that ori-
ginally straight lines are imaged on lines that converge
towards a vanishing point. It can be shown, see Appendix
A, that these lines intersect coordinate axes (x_s, y_s) of

20 the sensor (the image) in such a way that the inclina-
tions of the lines $(\Delta x_s/\Delta y_s, \Delta y_s/\Delta x_s)$ increase linearly
along the respective coordinate axis:

$$\begin{cases} \dfrac{\Delta x_s}{\Delta y_s} = kk_x \cdot x_s + mk_x \\[2mm] \dfrac{\Delta y_s}{\Delta x_s} = kk_y \cdot y_s + mk_{y_y} \end{cases}$$

     Appendix A also shows that an inclined plane that

25 gives rise to this perspective has a z-coordinate that
varies according to the formula:

$$z = C - kk_y \cdot x - kk_x \cdot y,$$

where x, y are spatial coordinates on the inclined plane,
that is on the surface of the product, and C is a scaling

30 factor.

22

In addition, Appendix A shows that perspective can be compensated for by means of the perspective transform:

$$
\begin{cases}
x = -\dfrac{x_s^t}{1 - kk_x \cdot x_s^t - kk_y \cdot y_s^t} \\[3mm]
y = -\dfrac{y_s^t}{1 - kk_x \cdot x_s^t - kk_y \cdot y_s^t}
\end{cases}
$$

where

5
$$
\begin{cases}
x_s^t = x_s - y_s \cdot mk_x \\
y_s^t = y_s - x_s \cdot mk_y
\end{cases}
$$

Before this transformation can be carried out, it is thus necessary to measure how the inclination of the raster pattern varies along the main vectors of the rotation-corrected set of dots (corresponding to the coordi-
10   nate axes x_s, y_s above). This inclination variation gives the desired values of mk_x, mk_y, kk_x, kk_y.

The inclination variation is measured via Fourier analysis. The set of dots is divided into four subsets around the image's/sensor's horizontal and vertical sym-
15   metry axes, the directions of which in practice essentially coincide with the directions of the main vectors. Each subset comprises dots in a half plane: above the horizontal symmetry axis, below the horizontal symmetry axis, to the right of the vertical symmetry axis, to the
20   left of the vertical symmetry axis. Unlike in the above-described detection of main vectors (step 101), the whole set of dots is used here for the division into subsets. The Fourier transform for the respective subsets is calculated in a corresponding way as for the detection of
25   main vectors. The sweeping of the frequency plane is carried out around the main vector and continues until all significant, adjacent peak values have been detected. In a corresponding way as for the detection of the main vectors, the position of the peak is calculated as the cen-
30   tre of gravity of all the calculation dots that are adjacent to each other in the frequency plane.

23

Figs 5A-5D show the calculation for the respective
half planes: upper (Fig. 5A), lower (Fig. 5B), left
(Fig. 5C), right (Fig. 5D), wherein black dots indicate
calculation dots without detection of any significant

5   peak value, black crosses indicate calculation dots with
detection of a significant peak value, and white stars
indicate the centres of gravity for the respective peaks.
These centres of gravity define subset main vectors, the
direction of which gives the inclination $(\Delta x_s/\Delta y_s,$

10   $\Delta y_s/\Delta x_s)$ of the set of dots in the respective half plane.
It should be pointed out that a complete frequency spec-
trum in two dimensions is not calculated. For the sake
of clarity it is, however, shown in the background of
Figs 5A-5D, wherein the central dark area forms the ori-

15   gin, that is $(u,v) = (0,0)$.

For the determination of mk_x, mk_y, kk_x, kk_y, initial
positions are also calculated for the subset main vectors
in the half planes. The initial positions are calculated
suitably as the centre of gravity of the set of unit

20   pulses in the respective half plane, since the centre of
gravity is relatively insensitive to variations in the
sensor's position, lost dots and a high degree of per-
spective. It is, however, possible instead to locate the
initial position at the geometric centre of the respec-

25   tive half plane. For the subset main vectors associated
with the left and right half planes, the intersections of
the subset main vectors with the horizontal symmetry axis
are calculated, and for the subset main vectors associat-
ed with the upper and lower half planes, the intersec-

30   tions of the subset main vectors with the vertical sym-
metry axis are calculated. The inclinations and inter-
sections are fitted to a straight line, from which mk_x,
mk_y, kk_x, kk_y are calculated. Fig. 6 shows a diagram of
the inclination along a symmetry axis as a function of

35   the position on this symmetry axis. Black crosses indi-
cate the measurement dots that were obtained by the

24

Fourier analysis as above based on the set of dots in
Fig. 4.

When mk_x, mk_y, kk_x, kk_y are known, a compensation for
perspective is implemented via the perspective transform

5   above. Fig. 7 shows the set of dots in Fig. 4 after com-
pensation for perspective. The corresponding virtual
raster has also been marked by broken lines.

Of course, it is possible to divide the set of dots
into other subsets than those described above for calcu-

10   lation of the inclination variation. More subsets than
two per main vector can be used for increased accuracy.

It should also be pointed out that other transforms
can be used to compensate for perspective. For example,
the above perspective transform can be replaced by the

15   approximating transform:

$$\begin{cases} x = -x_s^t \cdot \left(1 + kk_x \cdot x_s^t + kk_y \cdot y_s^t\right) \\ y = -y_s^t \cdot \left(1 + kk_x \cdot x_s^t + kk_y \cdot y_s^t\right) \end{cases}$$

The inclination variation of the rotation-compensat-
ed image can be measured by other methods than Fourier
analysis, for example by line fitting according to the

20   least-squares method. Unlike the Fourier-based method
described, which handles the set of dots as a single
entity, such line fitting methods require local decisions
concerning individual dots, for which reason they are
more sensitive to interference.

25   <u>Detection of Displacement and Compensation for this
(Steps 105-106)</u>

After the compensation for perspective, there
remains in principle only a constant displacement along
the main vectors. As shown in Fig. 7, the raster is

30   otherwise principally straight and essentially free of
rotation in the image plane. The displacements can be
measured as the phase in the Fourier analysis. What
remains is thus to measure this phase and to compensate
for it.

25

The Fourier transform for the whole set of dots is
calculated in a corresponding way to that for the detec-
tion of main vectors. The sweeping of the frequency plane
is carried out around the main vectors that were identi-
5   fied in step 101 above and continues until all signifi-
cant adjacent peak values have been detected. In a cor-
responding way to that for the detection of the main
vectors (step 101), the position of the peak is calcu-
lated as the centre of gravity of all the calculation
10   dots that are adjacent to each other in the frequency
plane. The result for the set of dots in Fig. 7 is shown
in Fig. 8, wherein again black dots indicate calculation
dots without detection of any significant peak value,
black crosses indicate calculation dots with detection
15   of a significant peak value, and white stars indicate
the centre of gravity of the respective peaks. It should
be pointed out that a complete two-dimensional frequency
spectrum is not calculated. For the sake of clarity it
is, however, shown in the background of Fig. 8, where-
20   in the central dark area forms the origin, that is
$(u,v) = (0,0)$. Fig. 8 also shows that the peaks in the
frequency plane become narrower after compensation for
perspective. The width of the peaks can thus be used to
determine whether there is in fact a need for perspective
25   compensation in an image.

At the same time as localisation of the respective
main vector via the absolute value of the Fourier trans-
form, the phase displacement along the respective main
vector from the Fourier transform's phase angle is
30   obtained, which is given by the ratio between its real
part and its imaginary part. This phase displacement is
eliminated by phase transformation of the set of dots,
whereupon a new projection is carried out along the most
recently determined main vectors. In addition, there is
35   scaling, on the basis of the length of the main vectors,
to ensure that the raster is based on integer coordi-
nates.

26

Fig. 9 shows the re-created image after phase com-
pensation. As shown, the virtual raster 5 is correctly
localised relative to the marks/unit pulses, which can
now be decoded for position information.

5   According to an alternative, there is no searching
for new main vectors in the frequency plane, since after
steps 101-102 these are relatively well-defined. Instead,
the phase angles are used for the Fourier transforms
which are calculated for the main vectors for the detec-

10   tion of these (step 101).

Optionally, a supplementary fine adjustment of the
identified raster pattern can be carried out after the
above-mentioned phase compensation. As each mark is a
known distance from its nominal position, each sequence

15   of marks along each main vector can be fitted, for exam-
ple via a least-squares method, to a line, which forms a
fine-adjusted raster line.

Device for Position Determination

An embodiment of a device for position determination
is shown schematically in Fig. 10. It comprises a casing

20   11 which has approximately the same shape as a pen. In
the short side of the casing there is an opening 12. The
short side is intended to abut against or to be held a
short distance from the surface on which the position
determination is to be carried out.

25   The casing contains principally an optics part, an
electronic circuitry part and a power supply.

The optics part comprises at least one light-emit-
ting diode 13 for illuminating the surface which is to be
imaged and a light-sensitive area sensor 14, for example

30   a CCD or CMOS sensor, for recording a two-dimensional
image. Optionally, the device can also contain an optical
system, such as a mirror and/or lens system. The light-
emitting diode can be an infrared diode and the sensor
can be sensitive to infrared light.

27

The power supply for the device is obtained from a battery 15, which is mounted in a separate compartment in the casing.

The electronic circuitry part contains an image-
5   processing means 16 for determining a position on the basis of the image recorded by the sensor 14 and in particular a processor unit with a processor which is programmed to read images from the sensor and to carry out position determination on the basis of these images.

10   In this embodiment, the device also comprises a pen point 17, with the aid of which ordinary pigment-based writing can be written on the surface on which the position determination is to be carried out. The pen point 17 can be extendable and retractable so that the user can
15   control whether or not it is to be used. In certain applications the device does not need to have a pen point at all.

The pigment-based writing is suitably of a type that is transparent to infrared light and the marks suitably
20   absorb infrared light. By using a light-emitting diode which emits infrared light and a sensor which is sensitive to infrared light, the detection of the pattern can be carried out without the above-mentioned writing interfering with the pattern.

25   The device can also comprise buttons 18, by means of which the device can be activated and controlled. It has also a transceiver 19 for wireless transmission, for example using infrared light, radio waves or ultrasound, of information to and from the device. The device can
30   also comprise a display 20 for displaying positions or recorded information.

A device for recording text is described in the Applicant's Swedish Patent No. 9604008-4. This device can be used for position determination if it is programmed in
35   a suitable way. If it is to be used for pigment-based writing, then it must also be given a pen point.

28

The device can be divided between different physical casings, a first casing containing components which are required for recording images of the position-coding pattern and for transmitting these to components which are

5   contained in a second casing and which carry out the position determination on the basis of the recorded image or images.

As mentioned, the position determination is carried out by a processor which thus must have software for

10   locating marks in an image and decoding them and for determining positions from the codes thus obtained. Based on the example above, a person skilled in the art will be able to design software which carries out the above-mentioned identification of the virtual raster pattern on

15   the basis of an image of a part of a position-coding pattern.

The device is preferably specified to be used with imaging conditions that lie within given limits. The imaging conditions can be defined as a permitted incli-

20   nation or tilting of the device (the sensor 14) relative to the surface that is to be imaged, for example a maximum of approximately 60°, and also a permitted rotation or skewing of the device around its longitudinal axis, for example in a range approximately ± 30° relative to a

25   reference position.

In the embodiment above, the pattern is optically readable and the sensor is therefore optical. The pattern can, however, be based on a parameter other than an optical parameter. In such a case, the sensor must of course

30   be of a type which can read off the parameter concerned. Examples of such parameters are chemical, acoustic or electromagnetic marks. Capacitive or inductive marks can also be used.

It is recognised that many variations are possible

35   within the scope of the present invention. The order of the above steps 101-106 can be varied within the scope of the invention. For example, detection of and compensation

29

for displacement can be carried out before detection of
and compensation for rotation and/or perspective. It is,
however, preferable to carry out the displacement steps
after the rotation and perspective processing steps,
5   since the displacement steps then become particularly
simple as far as calculations are concerned.

It is also possible to carry out the perspective
processing steps before the rotation processing steps,
suitably after having first converted the image into a
10   set of dots. Such a step for detection of perspective
can, for example, comprise the division of the image into
a plurality of subsets, and detection of at least one
direction in each subset, for example via Fourier ana-
lysis of the respective subsets. After this the change in
15   the detected directions across the image is evaluated for
the calculation of a transform that compensates for the
perspective in the image. The same transform can possibly
also compensate for rotation in the image plane. The eva-
luation can, for example, result in an identification of
20   the image's vanishing points, which are then transformed
into positions in infinity on the symmetry axes of the
image, for example by means of a perspective transform
of the type used in step 104 above. If the transformation
only compensates for perspective, this is suitably fol-
25   lowed by detection of rotation and compensation for this,
for example in accordance with the above steps 101-102.

In addition, the marks can have a different appear-
ance than described in the example above. Each mark can,
for example, consist of a line or an ellipse, which
30   starts at the virtual raster point and extends from this
to a particular position. Alternatively, some other sym-
bol can be used, such as a square, rectangle, triangle,
circle or ellipse, filled-in or not.

Nor do the marks need to be arranged along the
35   raster lines in an orthogonal raster but can also have
other arrangements, such as along the raster lines in
a raster with 60 degree angles, etc.

30

Rasters in the form of triangles or hexagons can
also be used, as shown in Figs 11 and 12. For example,
a raster with triangles, see Fig. 11, enables each mark
to be displaced in six different directions. In a hexa-
5   gonal raster (honeycomb raster), see Fig. 12, the marks
can be displaced in three different directions along
the raster lines. In these cases the main vectors of
the image are correspondingly more in number; in
Fig. 11 there are three dominant raster directions, and
10   in Fig. 12 there are three dominant raster directions.

As mentioned, the marks do not need to be displac-
ed along the raster lines but can be displaced in other
directions, for example in order to be located each in
a separate quadrant of a square raster pattern. In the
15   hexagonal raster pattern, the marks can be displaced in
four or more different directions, for example in six
different directions along the raster lines and along
lines which are at 60 degrees to the raster lines. In an
orthogonal raster, if necessary, only two displacements
20   can be used.

It must also be pointed out that depending upon the
available processing power, it can be possible to carry
out the above-mentioned Fourier analysis based on all the
actual image information that is recorded by the sensor.
25   Similarly it can, if the processor power is sufficient,
be possible to calculate a complete spatial frequency
spectrum in two dimensions, as shown in the background
to Figs 3, 5 and 8.

Those skilled in the art will also recognise that
30   the analysis in the frequency domain described above can
be implemented in a corresponding way in the wavelength
domain.

31

APPENDIX A

An optical system with amplification m images the spatial coordinate (x,y,z) on the sensor coordinate (x_s,y_s) according to the projection formula:

$$\begin{cases} x_s = -m \dfrac{x}{z} \\[2mm] y_s = -m \dfrac{y}{z} \end{cases} \tag{1}$$

5   Assume now two points in the space, P^1 and P^2. These lie on an inclined plane, the z-component of which is described by $z=z_0+ax+by$. The points P^1, P^2 lie symmetrically on each side of the x-axis, in the position x_0, and have the coordinates:

$$\begin{cases} P^1 = (x_0, y_0, z_0 + ax_0 + by_0) \\[2mm] P^2 = (x_0, -y_0, z_0 + ax_0 - by_0) \end{cases}$$

10

After projection in accordance with (1) the points P^1, P^2 end up on the sensor coordinates P_s^1, P_s^2:

$$\begin{cases} P_s^1 = -\dfrac{m}{z_0 + ax_0 + by_0}(x_0, y_0) \\[3mm] P_s^2 = -\dfrac{m}{z_0 + ax_0 - by_0}(x_0, -y_0) \end{cases}$$

We now calculate the inclination in the sensor,
15   $\Delta x_s/\Delta y_s$, between P_s^1 and P_s^2:

$$\frac{\Delta x_s}{\Delta y_s} = \frac{-m \cdot \left(\dfrac{x_0}{z_0 + ax_0 + by_0} - \dfrac{x_0}{z_0 + ax_0 - by_0} \right)}{-m \cdot \left(\dfrac{y_0}{z_0 + ax_0 + by_0} + \dfrac{y_0}{z_0 + ax_0 - by_0} \right)} = \tag{2}$$

$$\frac{(z_0 + ax_0 - by_0) \cdot x_0 - (z_0 + ax_0 + by_0) \cdot x_0}{(z_0 + ax_0 - by_0) \cdot y_0 + (z_0 + ax_0 + by_0) \cdot y_0} = \frac{-bx_0}{z_0 + ax_0}$$

A point P^3 in the centre of the x-axis, in position x_0, $P^3 = (x_0, 0, z_0 + ax_0)$, is imaged in accordance with (1) by:

32

$$P_s^j = -m \cdot \left(\frac{x_0}{z_0 + ax_0}, 0 \right) \equiv (x_s, 0) \qquad (3)$$

If we compare (3) with (2), we see that the inclination in the sensor is changed linearly in accordance with:

5
$$\frac{x_s}{y_s} = \frac{b}{m} x_s \qquad (4)$$

For reasons of symmetry, a corresponding equation applies to the inclination in the y-direction. Thus we now know:

$$\begin{cases} \dfrac{\Delta x_s}{\Delta y_s} (x_s) = \dfrac{b}{m} x_s \\[2ex] \dfrac{\Delta y_s}{\Delta x_s} (y_s) = \dfrac{a}{m} y_s \end{cases}$$

10   A raster situated on the inclined plane will, in addition to this strictly linear component, also contain a constant inclination, if the raster is not perfectly centred. We then get the following more general equation:

15
$$\begin{cases} \dfrac{\Delta x_s}{\Delta y_s} (x_s) = \dfrac{b}{m} x_s + mk_x \equiv kk_x \cdot x_s + mk_x \\[2ex] \dfrac{\Delta y_s}{\Delta x_s} (y_s) = \dfrac{a}{m} y_s + mk_y \equiv kk_y \cdot y_s + mk_y \end{cases} \qquad (5)$$

A general perspective can thus be described by the four variables mkx, mky, kkx, kky. It now remains to find the transform that restores the image coordinates to an orthogonal condition, given mkx, mky, kkx, kky. In order
20 to do this, we first subtract the constant part of the inclination (originating from the remaining rotation) so that the inclination at the coordinate axes is zero:

$$\begin{cases} x_s^t = x_s - y_s \cdot mk_x \\ y_s^t = y_s - x_s \cdot mk_y \end{cases} \qquad (6)$$

33

(1) is then used to reverse-transform these rotation-corrected coordinates. It is possible without the loss of generality to put z0=m, as this only results in a scaling of the coordinates. We have

5   from (1):
$$\begin{cases} x = \dfrac{z \cdot x_s^t}{-m} , \\ y = \dfrac{z \cdot y_s^t}{-m} \end{cases}$$

from (5):
$$\begin{cases} a = m \cdot kk_y \\ b = m \cdot kk_x \end{cases}$$

and the assumption: $z = m+ax+by$,

which gives us the non-linear equation system:

$$\begin{cases} x = \dfrac{\left(m + m \cdot kk_x \cdot x + m \cdot kk_y \cdot y\right) \cdot x_s^t}{-m} \\ y = \dfrac{\left(m + m \cdot kk_x \cdot x + m \cdot kk_y \cdot y\right) \cdot y_s^t}{-m} \end{cases}$$

10   whose solution is:

$$\begin{cases} x = -\dfrac{x_s^t}{1 - kk_x \cdot x_s^t - kk_y \cdot y_s^t} \\ y = -\dfrac{y_s^t}{1 - kk_x \cdot x_s^t - kk_y \cdot y_s^t} \end{cases}$$

where according to (6):

$$\begin{cases} x_s^t = x_s - y_s \cdot mk_x \\ y_s^t = y_s - x_s \cdot mk_y \end{cases}$$

34

CLAIMS

    1. A method for identifying a virtual raster pat-
5   tern (5) in an image of a plurality of marks (4), each
of which is associated with a respective intersection
(6) of raster lines (7) belonging to said raster pattern
(5), c h a r a c t e r i s e d in that the virtual raster
pattern (5) is identified via Fourier analysis of said
10   image.

    2. A method according to claim 1, comprising the
step of converting the image to a set of unit pulses
before the Fourier analysis, which unit pulses are plac-
ed at the positions of the marks (4) in the image.

15   3. A method according to claim 2, wherein each unit
pulse is placed at the centre of gravity of the corre-
sponding mark (4).

    4. A method according to any one of claims 1-3,
wherein said Fourier analysis comprises the steps of

20   calculating a spatial frequency spectrum in two
dimensions on the basis of said image,

    identifying at least two main vectors in said image,
based on said frequency spectrum, and

    identifying the raster lines (7) in said raster pat-
25   tern (5), on the basis of said main vectors.

    5. A method according to claim 4, wherein the spa-
tial frequency spectrum is calculated based on a two-
dimensional Fourier transform along at least two direc-
tions in said image.

30   6. A method according to claim 4 or 5, wherein the
spatial frequency spectrum is calculated on the basis of
a central part of the image.

    7. A method according to any one of claims 4-6,
wherein the step of identifying at least two main vec-
35   tors comprises the partial steps of

    localising in the spatial frequency spectrum posi-
tions of peaks that exceed a given threshold value, and

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selecting said at least two main vectors on the basis of said positions.

8. A method according to any one of claims 4-7, wherein the steps of calculating a spatial frequency spectrum and identifying main vectors therein comprise the partial steps of

changing the direction of a direction vector in steps within an angle range,

calculating at least one absolute value of the two-dimensional Fourier transform for the image on the basis of each such direction vector, and

identifying the absolute values that exceed said threshold value.

9. A method according to claim 8, wherein the length of the direction vector is changed within a frequency range that comprises the nominal spatial frequency of the raster pattern (5).

10. A method according to claim 9, wherein the length of the direction vector is changed in steps, pre-ferably in steps that are inversely proportional to a power of 2.

11. A method according to any one of claims 8-10, wherein the position of each of said peaks is localised by calculation of the centre of gravity of the absolute values that exceed said threshold value and that are adjacent to each other in the spatial frequency spectrum.

12. A method according to any one of claims 7-11, wherein the partial step of selecting at least two main vectors comprises

letting each position identify a candidate vector (c1-c3),

letting at least one current image transform, which provides a given change in the relationship between two vectors, operate on said candidate vectors (c1-c3), and

selecting as main vectors the candidate vectors that provide a required mutual relationship for said at least one current image transform.

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13. A method according to claim 12, wherein each current image transform corresponds to a given image relationship between a sensor (14) which records said image and an object (1) which is provided with said plu-
5   rality of marks (4).

14. A method according to claim 12 or 13, comprising the steps of sequentially letting a series of different current image transforms operate on said candidate vectors (c1-c3), at least until a required mutual relation-
10   ship is achieved between said candidate vectors.

15. A method according to any one of claims 12-14, wherein said raster pattern (5) is identified on the basis of the image transform that gave rise to the required relationship between the candidate vectors
15   (c1-c3).

16. A method according to claim 12 or 13, wherein the current image transform is selected on the basis of an earlier image transform that gave rise to the required relationship for a previous image.

20   17. A method according to any one of claims 4-16, wherein said main vectors are selected on the basis of earlier main vectors that were determined for a previous image.

18. A method according to any one of the preceding
25   claims, comprising the step of transforming said marks (4) with the main vectors as bases for producing a rotation-corrected image in which rotation of the marks (4) over the plane of the image is essentially eliminated.

19. A method according to claim 18, comprising the
30   additional step of compensating for perspective in the rotation-corrected image.

20. A method according to claim 18 or 19, comprising the additional steps of
     determining the width of the peaks corresponding to
35   the main vectors in a spatial frequency spectrum of said rotation-corrected image, and

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compensating for perspective in the rotation-cor-
rected image if the width exceeds a given width value.

21. A method according to claim 19 or 20, wherein
the step of compensating for perspective comprises the
5   partial steps of
measuring an inclination variation for the raster
pattern along each main vector in the rotation-corrected
image,
calculating a perspective transform on the basis of
10   the measured inclination variation, which perspective
transform essentially eliminates said inclination varia-
tion, and
producing a perspective-corrected image by means of
the perspective transform.
15   22. A method according to claim 21, wherein the
measurement of the inclination variation for the raster
pattern along a selected main vector comprises the par-
tial steps of
via Fourier analysis of at least two subsets of the
20   rotation-corrected image distributed along the selected
main vector, calculating at least one subset main vector
for each subset,
identifying an initial position in the associated
subset for each subset main vector, and
25   calculating the inclination variation along the
selected main vector on the basis of said subset main
vectors and initial positions.
23. A method according to claim 22, wherein the ini-
tial position is identified on the basis of the centre of
30   gravity of the marks incorporated in the respective sub-
set.
24. A method according to any one of claims 18-23,
comprising the additional steps of
measuring the phase displacement of the rotation-
35   corrected or perspective-corrected image along the
respective main vector via Fourier analysis of the
rotation-corrected or perspective-corrected image, and

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localising the raster pattern (5) relative to said
marks (4) in the image on the basis of the measured phase
displacements.

25. A method according to claim 24, comprising the
5   additional steps of
calculating a normalising transform that places the
intersections (6) of the raster pattern (5) a given dis-
tance apart, and
operating the normalising transform on the image in
10 order to produce a normalised image.

26. A method for identifying a virtual raster pat-
tern (5) in an image of a plurality of marks (4), each of
which is associated with a respective intersection (6) of
raster lines (7) belonging to said raster pattern (5),
15 c h a r a c t e r i s e d by the steps of
detecting main vectors of the image via Fourier ana-
lysis,
compensating for rotation in the plane of the image
on the basis of said main vectors,
20   detecting a perspective in the image,
if necessary, compensating for said perspective, and
identifying the virtual raster pattern (5) on the
basis of said main vectors.

27. A computer-readable computer program product
25 which comprises a computer program with instructions for
causing the computer to implement a method according to
any one of claims 1-26.

28. A device for position determination, comprising
a sensor (14) for producing an image of a partial surface
30 of a surface (2) which is provided with a position code
in the form of a plurality of marks (4), each of which is
associated with one of a plurality of intersections (6)
belonging to a virtual raster pattern (5), and an image-
processing means (16) which is arranged to calculate
35 a position for the partial surface based on a subset of
the surface (2), the image-processing means (16) being

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designed to identify the virtual raster pattern (5) in accordance with any one of claims 1-26.

29. A device according to claim 28, which is hand-held.

5   30. A device according to claim 28 or 29, which has a means (19) for wireless transmission of position information.
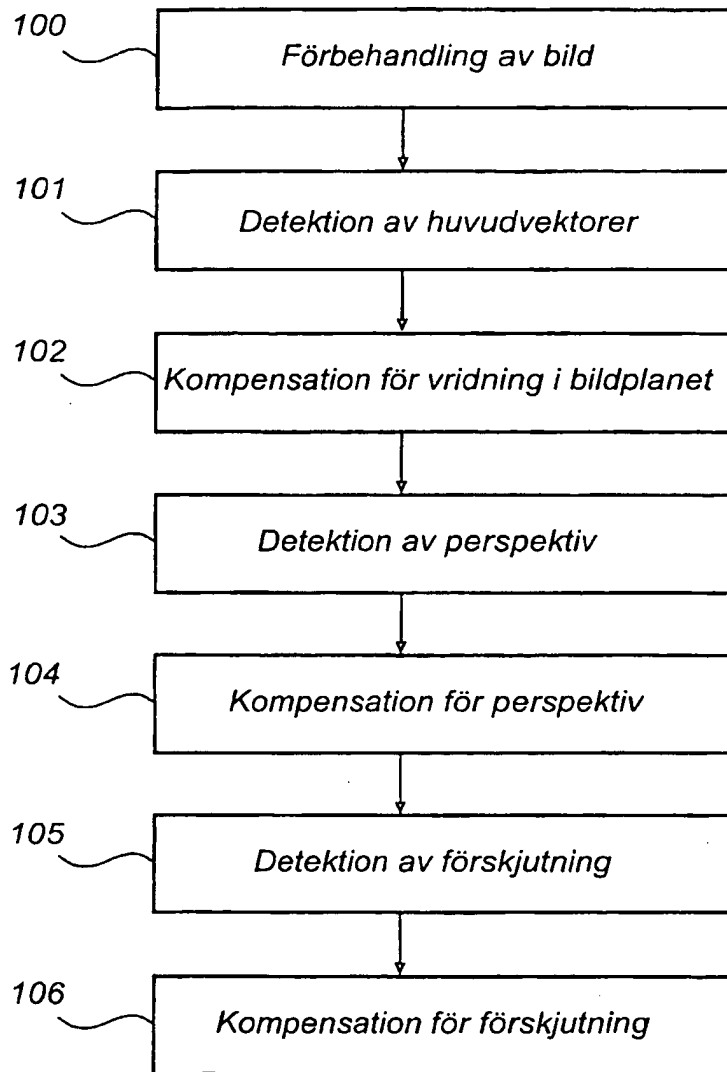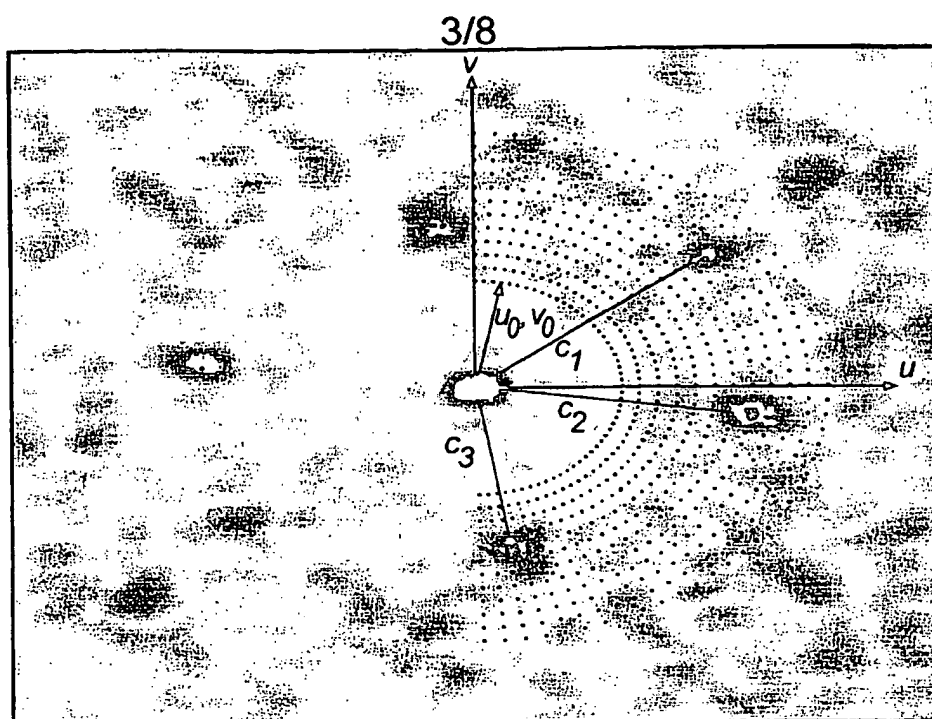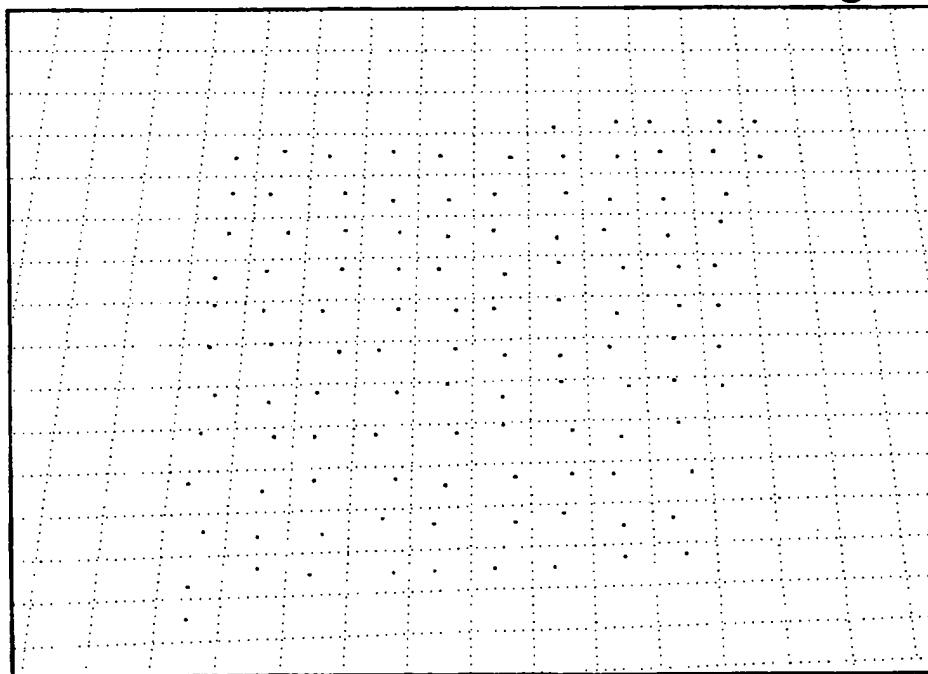
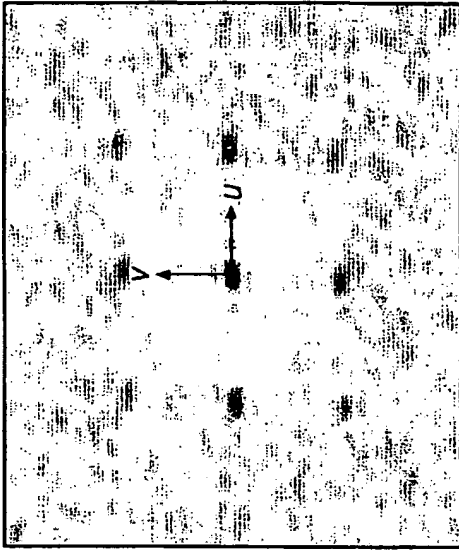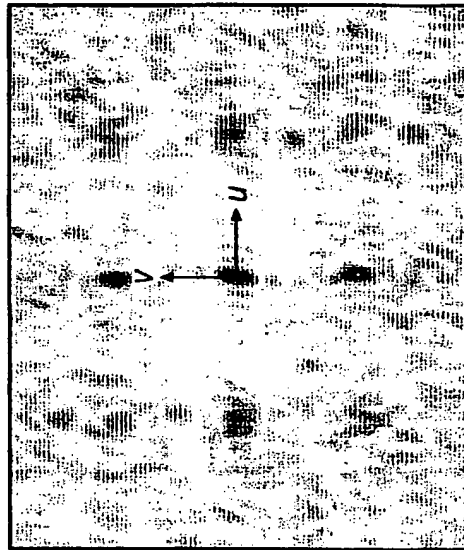1/8

Fig. 1a

Fig. 1b

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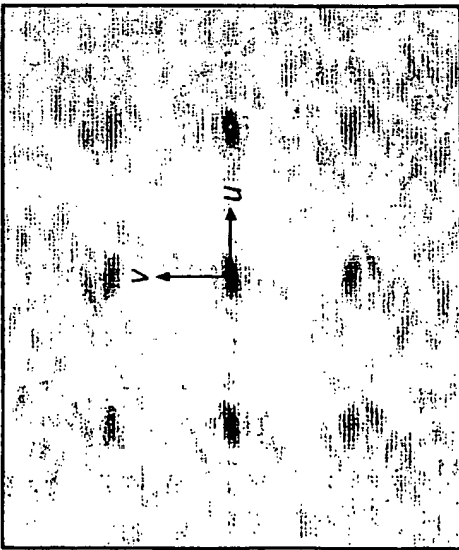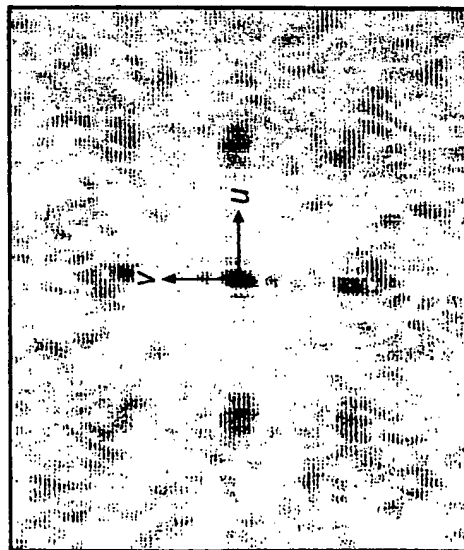

Fig. 2

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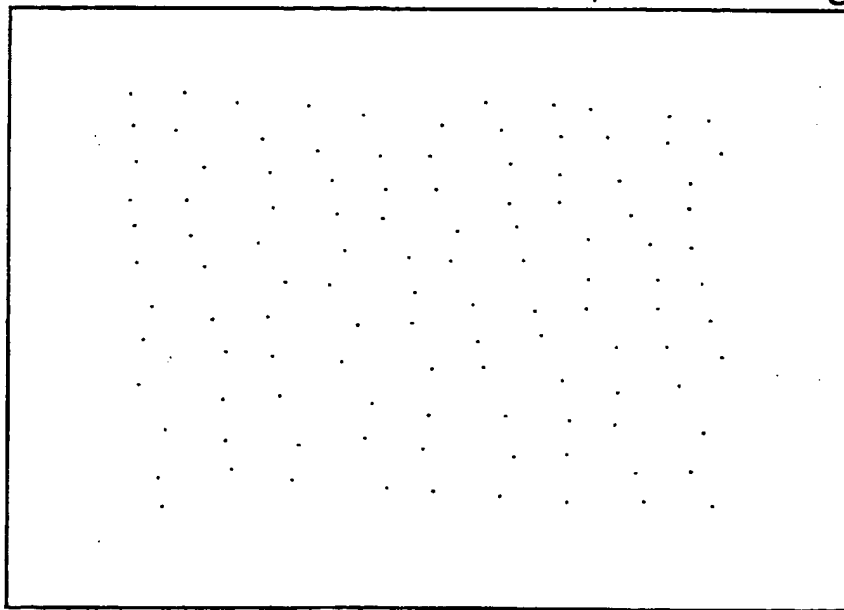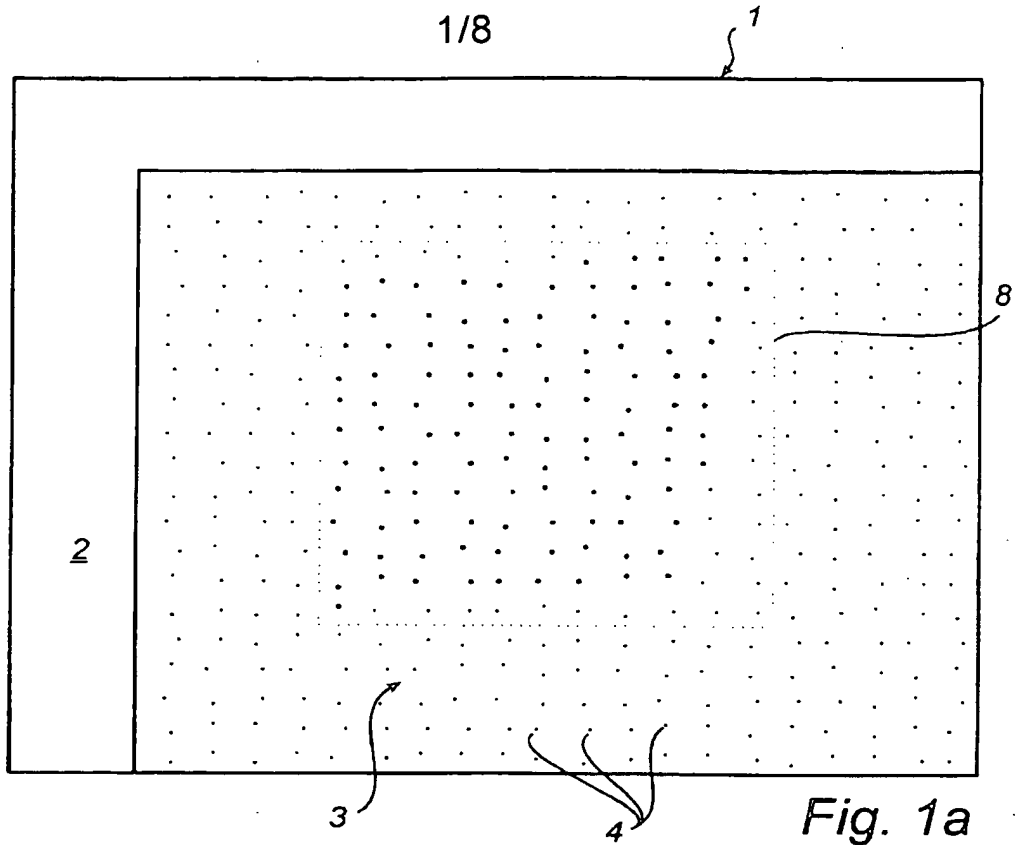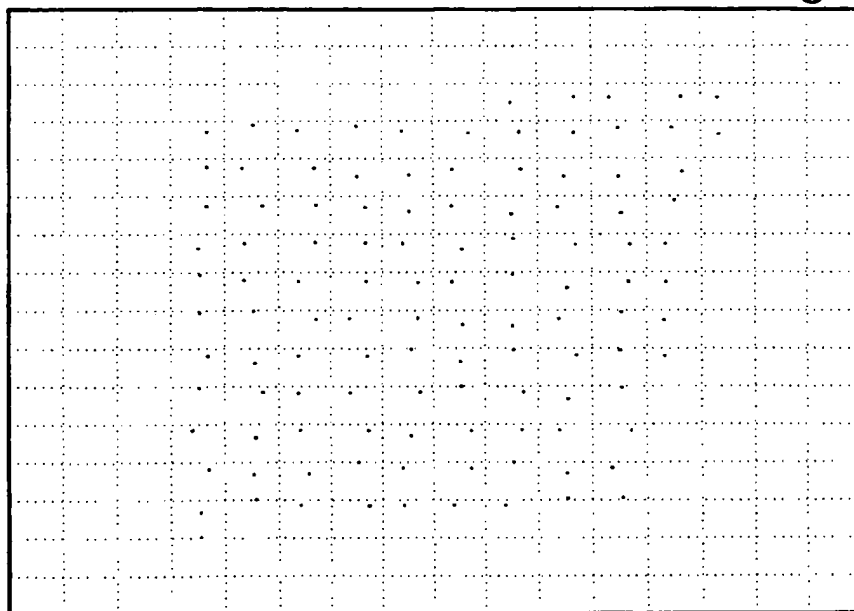

Fig. 3

Fig. 4
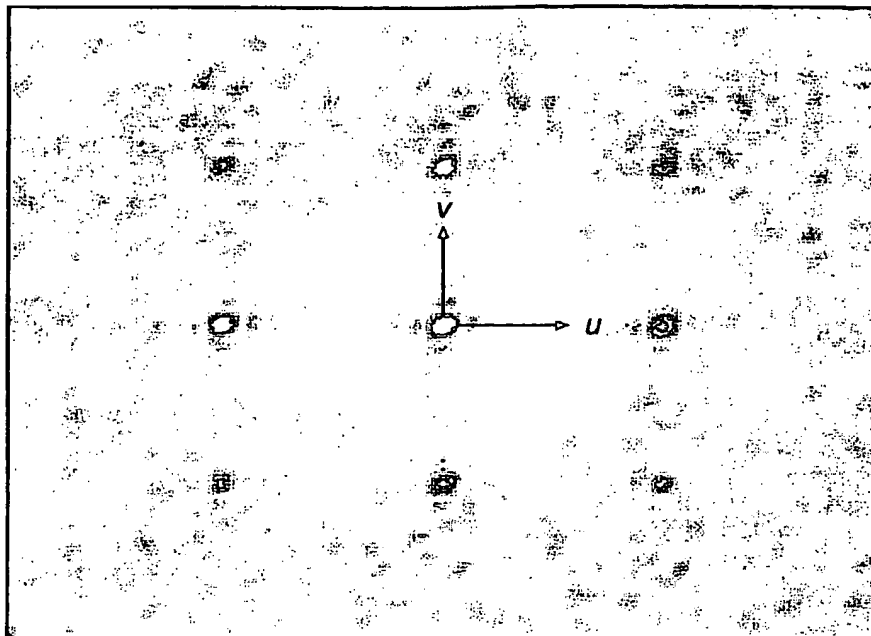
Fig. 5b

Fig. 5d

Fig. 5a

Fig. 5c

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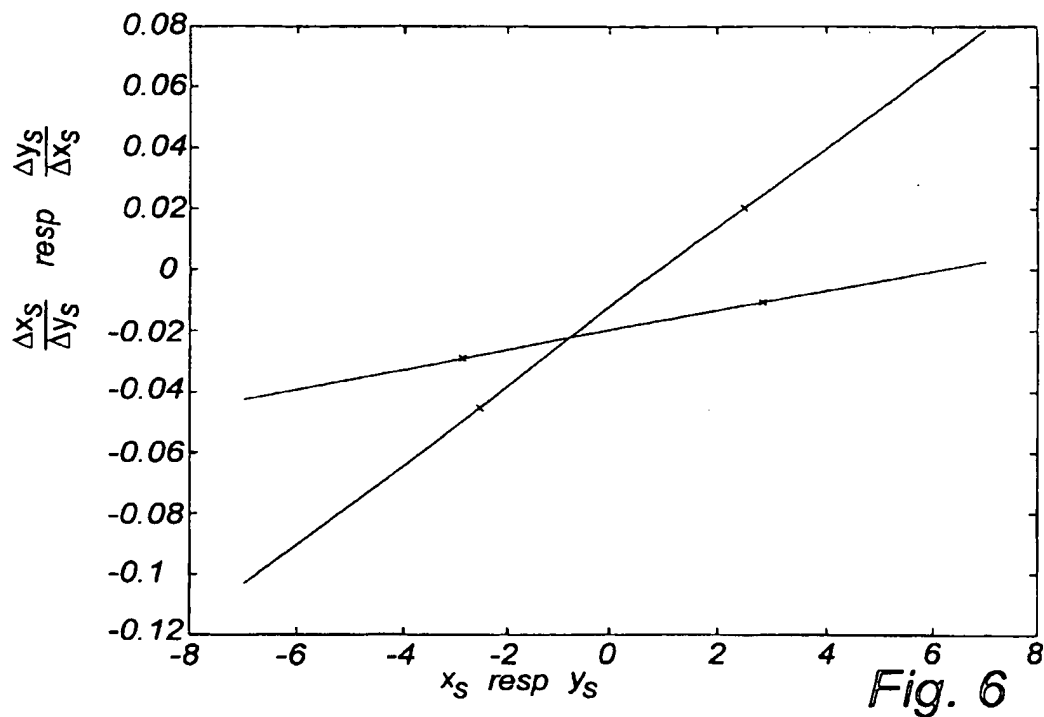
Fig. 6

Fig. 7

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Fig. 8

Fig. 9

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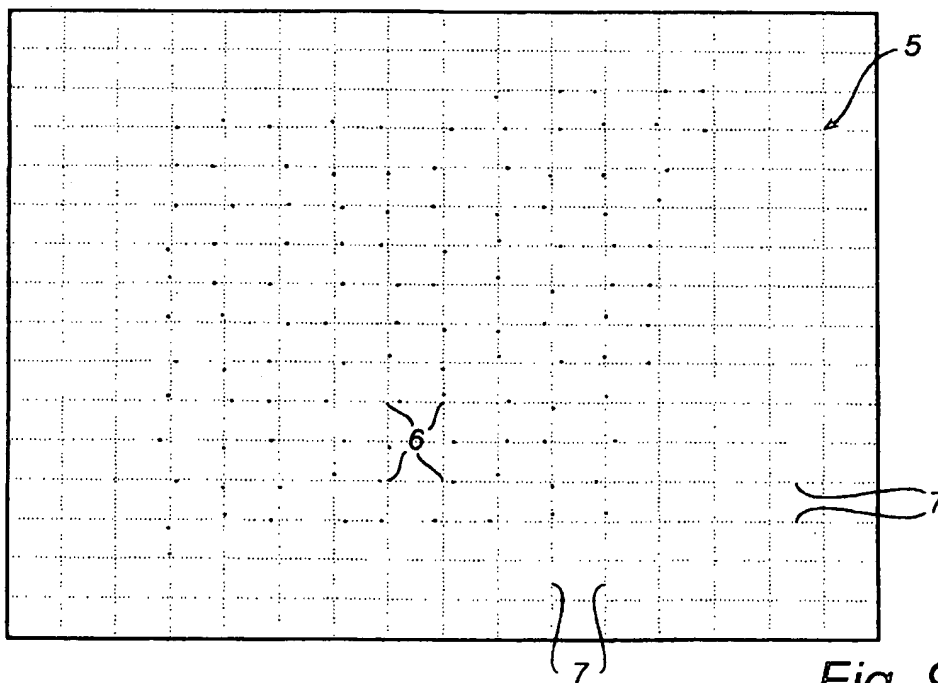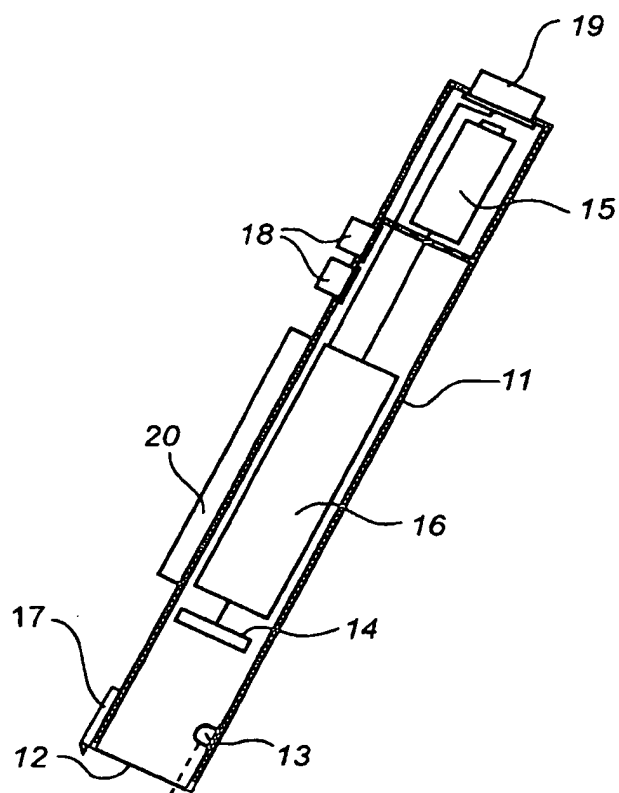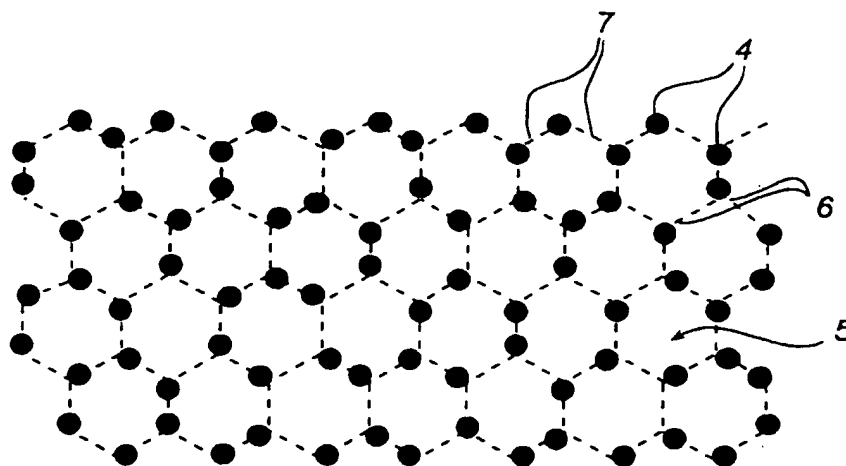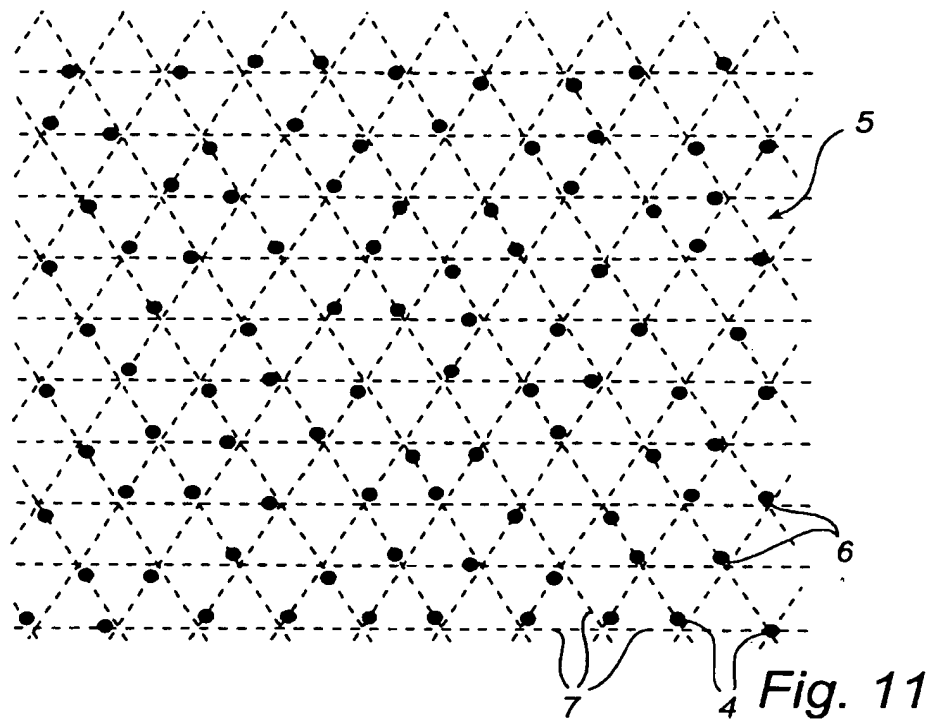

Fig. 10

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Fig. 11

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/00604

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G06K 19/06, G06F 3/033, G06K 11/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G06K, G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI-DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5786583 A (P.A. MALTSEV), 28 July 1998 (28.07.98), column 1, line 63 - column 2, line 10; column 2, line 20 - column 3, line 12; column 4, line 10 - line 60, figure 1, claim 1, abstract	1-3,27-30
A		4-26
	--	
A	US 5091966 A (D.S. BLOOMBERG ET AL), 25 February 1992 (25.02.92), column 12, line 55 - column 13, line 2, figures 1,5, claims 1-2, abstract	1-30
	--	

X	Further documents are listed in the continuation of Box C.		X	See patent family annex.

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*     Special categories of cited documents:
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      cited to establish the publication date of another citation or other
      special reason (as specified)
"O"   document referring to an oral disclosure, use, exhibition or other
      means
"P"   document published prior to the international filing date but later than
      the priority date claimed
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"T"   later document published after the international filing date or priority
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      considered novel or cannot be considered to involve an inventive
      step when the document is taken alone
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      considered to involve an inventive step when the document is
      combined with one or more other such documents, such combination
      being obvious to a person skilled in the art
"&"   document member of the same patent family
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Date of the actual completion of the international search	Date of mailing of the international search report
13 July 2001	16 -07- 2001

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

	International application No.
	PCT/SE 01/00604

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5555313 A (J.ZHENG ET AL), 10 Sept 1996 (10.09.96), column 1, line 47 - column 2, line 25; column 4, line 51 - line 57, figures 2-4, claim 1, abstract	1-30

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INTERNATIONAL SEARCH REPORT

Information on patent family members

02/07/01

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				JP	10021322 A	23/01/98
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				JP	4233678 A	21/08/92
				JP	7078819 B	23/08/95
US	5555313	A	10/09/96	US	5566245 A	15/10/96